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OPTIMIZATION OF PID CONTROLLER GAINS OF AN AIRCRAFT PITCH CONTROL SYSTEM USING PARTICLE SWARM OPTIMIZATION ALGORITHM

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ABSTRACT

In this paper, a "Proportional-Integral-Derivative" (PID) controller used in a aircraft pitch control system is optimally tuned to control the output response so as to obtain a much more stable and optimized transient response is studied. The objective is to obtain a cohesive, sturdy and controlled system by tuning the PID controller using PSO algorithm. The obtained result is compared against the results obtained by re-tuning the same system with standard PID tuning algorithm and proves to give more suitable results. Results obtained establishes that, if we tune the PID controller of the given system using PSO algorithm we get reduced percentage of overshoot, reduced rise time, settling time, peak and hence system is more stable and less stagnant with PSO than the same system tuned with standard PID tuning algorithm.

KEYWORDS: PID Controller, PSO Algorithm, Aircraft Pitch Control System & Mat Lab Auto Tuning

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Original Article

INTRODUCTION

Several control systems of aircraft and other control industries use scholastic controller like PID to upgrade the systems features and dynamic conduct and to improvise the stability assay and performance dynamics of the aircraft. The flight envelope safety is being enhanced by optimal tuning of parameters of PID controller, for aircraft's dynamics of pitch control. The wide significance of the PID controllers can be attributed, to their admirable performance, for a wide operating condition ranges, and simplicity of functioning, which lets engineers operate them in a simple, straightforward manner and commonness, with which it is anticipated amongst researchers and professionals in the area of process control industries. PID controller calculates the net value of inaccuracy, which is the discrepancy in output result of the system and optimum reference value. It reduces the error value, by modulating the inputs of the pitch control system.

PID controller gains are 3-term control parameters – the Proportional, Integral and Derivative parameters denoted as K_P, K_I, and K_d. The output of the controller is presented in terms of error in value of the controller, the extent to which it deviates from the standard result achieved, calculating of rate of oscillation of the system. The structure of PID controller and is represented by-

$$X\,(s) = K_P + K_I(1/s) + K_{ds} = K_P[1 + (1/Ts) + T_{ds}] \quad (1)$$

Where K_P is proportional gain parameter, K_I is integral parameter gain, K_d derivative gain parameter, T_I is time constant integral and T_d is time constant derivative. A proportional controller (K_P) reduces the rise time and it also reduces, but doesn't get rid of the steady-state error. An integral parameter (K_I) eliminates the steady-state error, for a constant or step input, but it may slow down the transient response for the system. A derivative control

(K_d) increases the stability of the system, reduces the overshoot percentage, and improves the transient response". These correlations are not precisely accurate, because K_P, K_I& $K_d$values, depend on each other and modifying one of these variables, can change the values of others.

Despite of widespread application of PID controller's one specific limitations is that there is no efficient method to tune this type of controller. Various methods have been proposed over the years to tune the PID controllers. Some of them will be discussed later on in this paper.

As mentioned before for this paper the swarm optimisation algorithm of PSO is used to tune PID gains/parameters (Kp, Ki, Kd), which in turn is used to optimize the longitudinal pitch control parameters, for an aircraft pitch control system. The aim of this paper is to establish that, if we tune the PID controller using PSO technique, we get less overshoot, less rise time, less settling time, less peak time and hence, system is less stagnant and much more stable, compared to Mat lab auto tuning algorithm.

Pitch Control System Using PID

Over the years, flight control systems are being engineered, by employing mathematical specimen of the airplane linearized for several dynamic flight parameters modified, with the operating situations. The purpose of the work developed is, to modulate the pitch rate of an airplane for pitch control, in order to give the system better stability related characteristics, when the airplane is upward nosed or downward nosed. The system for control of pitch rate discussed in this paper, is demonstrated in Figure. 1. Here, "X_b, Y_b and Z_b" denote the aerodynamics force elements. "θ, Φ and δ_e" denote the orientation of aircraft, w. r. t the earths-axis model and the angle of deviation of the elevator.

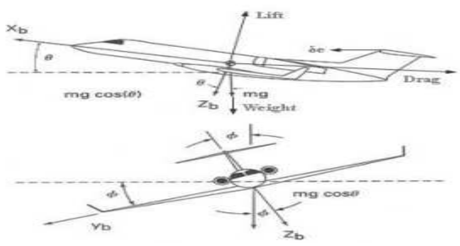

Figure 1: Aircrafts dynamic Pitch control Model Parameters [7]

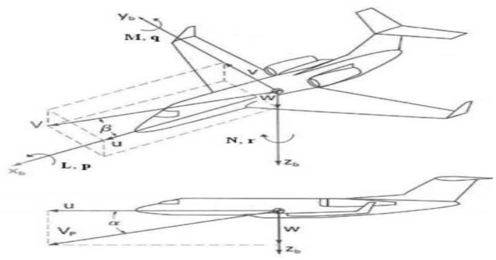

Figure2: velocity, force and moment components in rigid body coordinate axes [7]

Figure.2, shows the velocity, force and moment constituents in the body fixed coordinate of aircraft system. The aerodynamics moment constituents for pitching, yawing and rolling axes are denoted as M, N and L The term, q, r and p represent the angular rates with respect to pitching, yawing and rolling axis while term u, v, w denote the velocity components of rolling, pitching and yawing axes. Angles α and β denote the angle of attack and sides lip values respectively

The assumptions considered for the given aircraft model used in this paper are

The assumptions and equations considered for the modelling process are

- A constant state of cruising at steady altitude and velocity, therefore the aircrafts drag and thrust value nullify each other and lift generated and weight balances one another
- pitch modification doesn't affect velocity of the airplane in any manner

- **Rolling rate** $p = \dot{\Phi} - \dot{\psi} S_\theta$
- **Rate of yaw**, $q = \dot{\theta} C_\Phi + \dot{\psi} C_\theta S_\Phi$
- **Pitch Rate** $r = \dot{\psi} C_\theta C_\Phi - \dot{\theta} S_\Phi$
- **Pitch Angle**, $\dot{\theta} = q C_\Phi - r S_\Phi$
- **Angle of Roll** $\dot{\Phi} = p + q S_\Phi T_\theta + r C_\Phi T_\theta$
- **Angle of Yaw** $(q S_\Phi + r C_\Phi) \sec\theta$

We refer to the Figure 1 and Figure 2, from which dynamic equations of force and moment are determined.

$$X - mgS_\theta = m(\dot{u} + qv - rv) \quad (1)$$

$$Z + mgC_\theta C_\Phi = m(\dot{w} + pv - qu) \quad (2)$$

$$M = I_y \dot{q} + rq(I_x - I_z) + I_{xz}(p^2 - r^2) \quad (3)$$

Equations of [1] [2] and [3] are being linearized with “small disturbance theory”. The equations are replaced by a particular standard variable, with a perturbation or disruption, as it is shown below.

$$u = u_o + \Delta u \quad v = v_o + \Delta v \quad w = w_o + \Delta w$$
$$p = p_o + \Delta p \quad q = q_o + \Delta q \quad r = r_o + \Delta r$$
$$X = X_o + \Delta X \quad M = M_o + MY \quad Z = Z_o + \Delta Z$$
$$\delta = \delta_o + \Delta \delta$$

For our convenience, we assume the standard conditions of flight to be balanced and the propulsive forces as constant. This implies that, " $v_0 = p_0 = q_0 = r_0 = \Phi_0 = \psi_0 = w_0 = 0$". From linearization the eons [4], [5] and [6] are being given below

$$\left(\frac{d}{dt} - X_u\right)\Delta u - X_w \Delta w + (g\cos\theta_o)\Delta\theta = X\delta_e \Delta\delta_e \quad (4)$$

$$-Z_u \Delta u + \left[(1 - Z_{\dot{w}})\frac{d}{dt} - Z_w\right]\Delta w - \left[(u_o + Z_q)\frac{d}{dt} - g\sin\theta_0\right]\Delta\theta = Z_{\delta e}\Delta\delta_e \quad (5)$$

$$-M_u \Delta u - \left(M_{\dot{w}}\frac{d}{dt} + M_w\right)\Delta w + \left(\frac{d^2}{dt^2} - M_q\frac{d}{dt}\right)\Delta\theta = M_{\delta e}\Delta\delta_e \quad (6)$$

We manipulate values of eqns [4], [5] and [6] and substitute the value of parameters of the derivatives of longitudinal stability, thus we obtain this particular transfer function, for the rate of change of pitch, to the change in angle of deflection of the elevator is being denoted as [7]

$$\frac{\Delta q(s)}{\Delta \delta_e(s)} = \frac{-(M_{\delta} + M_{\dot{\alpha}} Z_{\delta}/u_0)s - (M_{\alpha} Z_{\delta}/u_0 - M_{\delta} Z_{\alpha}/u_0)}{s^2 - (M_q + M_{\dot{\alpha}} + Z_{\alpha}/u_0)s + (Z_{\alpha} M_q/u_0 - M_{\alpha})} \tag{7}$$

The transfer function for the rate of change of angle of pitch, to the rate of deflection of the elevator can be acquired, from the pitch rate variance to the change in angle of elevator in the following way.

$$\Delta q = \Delta \dot{\theta} \tag{8}$$

$$\Delta q(s) = s\Delta \theta(s) \tag{9}$$

$$\frac{\Delta \theta(s)}{\Delta \delta_e(s)} = \frac{1}{s} \cdot \frac{\Delta q(s)}{\Delta \theta(s)} \tag{10}$$

Thus the transfer function for the given airplane pitch control system is achieved in eqns [11] and [12], respectively.

$$\frac{\Delta \theta(s)}{\Delta \delta_e(s)} = \frac{1}{s} \cdot \frac{-(M_{\delta} + M_{\dot{\alpha}} Z_{\delta}/u_0)s - (M_{\alpha} Z_{\delta}/u_0 - M_{\delta} Z_{\alpha}/u_0)}{s^2 - (M_q + M_{\dot{\alpha}} + Z_{\alpha}/u_0)s + (Z_{\alpha} M_q/u_0 - M_{\alpha})} \tag{11}$$

$$\frac{\Delta \theta(s)}{\Delta \delta_e(s)} = \frac{11.7304s + 22.578}{s^3 + 4.9676s^2 + 12.941s} \tag{12}$$

This transfer function block, along with the actuator is implemented using PID to give the final model, as it is shown in the below figure -:

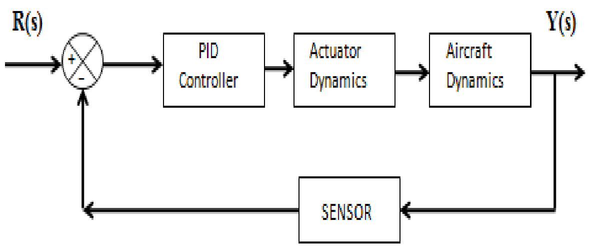

Figure 3: Pitch Control System Using PID Controller [6]

A proportionality parameter gives the signal error value, through the constant gain aspect indicators. An integral parameter helps decreasing steady-state error and a derivative parameter improves the transient feedback of the aircraft system. A collective PID controller generally gives more desirable solution than independent of P, I and D parameters. Choosing of gain value, for the PID controllers can be obtained from a separate closed loop method of tuning

- An aircraft pitch control system provides control action for longitudinal pitch modulation of the aircraft.
- The control is provided in the form of pitch rate and pitch angle at a specific point of flight

PID Tuning Methods

The various primary tuning methods employed these days are “Ziegler Nichols” method, “Modified Ziegler Nichols” method, “Asstrom and Haggland” method, “Tyrus Leuben” methods etc.

PID Tuning Using PSO for Pitch Control System

PSO is swarm intelligence based indeterminate optimization method constructed and influenced by social behaviour of flock of bird or school of fish. PSO simulates the behaviours of these social systems. For PSO, we consider a particular solution as a "bird" in the search territory. We name it "particle". Every single particle has a particular value of fitness which is calculated by the fitness function which we want to optimize; every single particle has a particular velocity which directs its flying. The particles fly through the problem space by following the particle with the best fitness function PSO computes a group of particles (solutions) in random space and after that inspects for optimum value by revising he values through multiple iterations. For each iteration, every single particle is updated by pursuing the two "best" results. The 1st value is the best result (fitness), it has attained so far. (That value of fitness is saved.) This value is known as “pbest”. Another value "best", that is pursued by the particle swarm optimizer is the best result, being attained so far by any particle in the whole group. This value is a global best and named “gbest”. If one particular particle takes portion of the population as its metaphoric acquaintances, the optimum value is a local best and is called l best.

After the two best values are obtained, the velocity and position of each particle is updated with the given equation (a) and (b).

- $V_p = V_p$ + A1 * rand() * (pbest – current value) + A2 * rand() * (gbest–current value)(i)
- Current value = current value + V_p (ii.)

Vp is the velocity of the particle; current value is the present particle fitness (solution). “pbest” and “gbest” are defined as given earlier, rand () is a random value between (0,1). A1, A2 are learning factors which in several cases are A1= A2 = 2

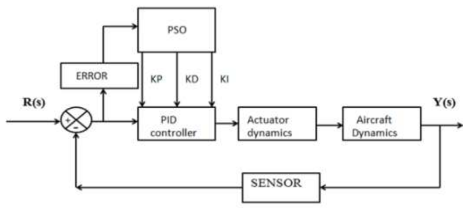

Figure 4: Pitch Control System with PID Controller using PSO [4]

This is the final model developed for the system using PSO. As shown above here PSO algorithm is used as a function block with a function caller to tune the PID controller and thus give a tuned value of Kp, Ki and Kd, which is then fed into the system to give us the desired transient response.

RESULT & DISCUSSIONS

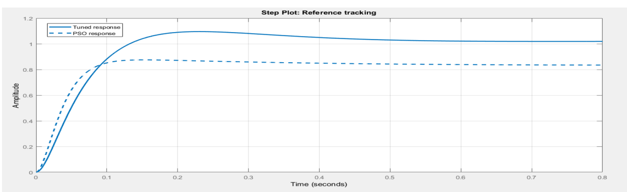

Figure 5: PSO Tuned Response Vs Matlab Auto Tuned Response

The following graph displays the final transient response and compares obtained PSO response with Matlabauto tuned response

From the above Amplitude vs. Time graph we can observe that the PSO tuned response for the aircraft pitch control looks way more stable than the Matlabauto tuned response, for the same system. This, in particular, is an extremely important result because, a more stable system would mean enhancement in the manoeuvrability or control of the aircraft, in control of pitch rate. Having a good manoeuvrability is an extremely vital part for an aircraft, during its flight because; the safety of the flight directly depends on it. Moreover, the efficiency of the aircraft also increases due to a more stable pitch control system, thus reducing the cost of operations.

From the two transient responses above, we obtain the performance parameters - Rise time, Peak time, Settling time, Maximum Overshoot percentage. We write down these parameters in Tabular form for analysis and then compare them.

PID Controller Parameters

PID Parameters	Auto tuned	PSO tuned
K_P	7.655	0.63
K_I	11.82	0.0504
K_d	1.189	1.9688

Performance Parameters

	Auto Tuned	PSO tuned
Rise Time	0.0885	0.0504
Settling Time	1.15	0.329
Overshoot %	9.52	4.31
Peak	1.1	0.875

CONCLUSIONS

We can see from the graph and tabular results above that the transient response for the pitch control system model with PSO gives much more stable and optimized response compared to the auto tuned response obtained for the same system as all the performance parameters obtained–Rise time, Settling time, Overshoot percentage and peak are much less for PSO tuned response than Mat lab auto tuned response.

The proves that, for the given aircraft pitch control the results obtained from PSO algorithm are much more efficient and adequate than those obtained from Matlabauto tuning algorithm.

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REFERENCES

1. *"P. G. Medewar; R. K. Munje “PSO based PID controller tuning for PMDC motor” 2015 International Conference on Energy Systems and Applications Year: 2015Pages: 522 - 526, DOI: 10.1109/ICESA.2015.7503404*
2. *Guan-Yan Chen; Jau-Woei Perng; Li-Shan Ma “DSP based BLDC motor controller design with auto tuning PSO-PID algorithm” 2015 IEEE/SICE International Symposium on System Integration (SII)Year: 2015Pages: 766 - 770, DOI: 10.1109/SII.2015.7405076*

3. *Saleh M. Bamasak; Ahmed Bensenouci "Tuning of Fractional Order PID controller for TCSC-based stabilizer using PSO for power system oscillation damping" 2014 IEEE International Energy Conference (ENERGYCON)Year: 2014Pages: 262 - 266, DOI: 10.1109/ENERGYCON.2014.6850438*

4. *Venkatesh Kumar.N, et al., Identification of Aircraft Pitch Control System and Design and Implementation of a Digital Compensator, International Journal of Electrical and Electronics Engineering Research, Volume 3, Issue 1, March 2013, pp. 307-314*

5. *Bouarroudj Noureddine; Boukhetala Djamel; Fares Boudjema "Tuning fuzzy fractional order PID sliding-mode controller using PSO algorithm for nonlinear systems" 3rd International Conference on Systems and Control Year: 2013Pages: 797 - 803, DOI: 10.1109/ICoSC.2013.6750949*

6. *Suppachai Howimanporn; Sunphong Thanok; Sasithorn Chookaew; Warin Sootkaneung "Speed control technique for conveyor using PSO based PID with programmable logic controller" 2016 IEEE/SICE International Symposium on System Integration (SII)Year: 2016Pages: 670 - 675, DOI: 10.1109/SII.2016.7844076*

7. *G. Sudha and S. N. Deepa "Optimization for PID Control Parameters on Pitch Control of Aircraft Dynamics Based on Tuning Methods" ∗Appl. Math. Inf. Sci. 10, No. 1, 343-350 (2016)*

8. *Nurbaiti Wahid and Nurhaffizah Hasan "Self-tuning Fuzzy PID Controller Design for Aircraft Pitch Control" 2012 Third International Conference on Intelligent Systems Modelling and Simulation*

9. *Vishal Dr. Jyoti Ohri "GA Tuned LQR and PID Controller for Aircraft Pitch Control" Power Electronics (IICPE), 2014 IEEE 6th India International Conference*

10. *S. J. Bassi, M. K. Mishra and E. E. Omizegba "Automatic tuning of proportional– integral–derivative (pid) controller using particle swarm optimization (pso) algorithm" International Journal of Artificial Intelligence & Applications (IJAIA), Vol.2, No.4, October 2011*

11. *S. Morkos, H. Kamal "Optimal Tuning of PID Controller using Adaptive Hybrid Particle Swarm Optimization Algorithm"Int. J. of Computers, Communications & Control, ISSN 1841-9836, E-ISSN 1841-9844 Vol. VII (2012), No. 1 (March), pp. 101-114*

12. *Sulochana Wadhwani, Veena Verma "Evolutionary Computation Techniques Based Optimal PID Controller Tuning" [International Journal of Engineering Trends and Technology (IJETT) - Volume4 Issue6- June 2013*

13. *Aman Jacknoon,M. A. Abido "Ant Colony based LQR and PID tuned parameters for controlling Inverted Pendulum" 2017 International conference on Communication, Control, Computing and Electronics Engineering (ICCCCEE) Year: 2017*

14. *Wufan Wang; Xiaming Yuan; Jihong Zhu "Automatic PID tuning via differential evolution for quadrotor UAVs trajectory tracking" 2016 IEEE Symposium Series on Computational Intelligence (SSCI)Year: 2016*

15. *Hanif Halim; I. Ismail "Online PID controller tuning using tree physiology optimization" 2016 6th International Conference on Intelligent and Advanced Systems (ICIAS)Year: 2016*

16. *Pengfei Li, Changsheng Zhu "Research on PID Tuning Method of Magnetically Suspended Rotor System Based on IMC"2016 IEEE Vehicle Power and Propulsion Conference (VPPC) Year: 2016* "